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State of knowledge of research in the Guinean forests of West Africa region

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ABSTRACT

The Guinean forests of West Africa (GFWA) region is of highest conservation value in Africa and worldwide. The aims of this review are to systematically identify and collate studies focusing on the environment in the region. We found that, after Google Scholar search, in over 112,000 results for 17 disciplines, three countries (Nigeria, Cameroon and Togo) were subjected to much more investigations than the other countries. Guinea, Liberia, and Sierra Leone were the least studied countries, and overall there was a significant West to East increasing trend for all seven considered disciplines (Ecology, Zoology, Botany, Conservation biology, Pollution, Climate change and Ecological economy) in terms of number of results. Within 'Ecology' 'macroecology and biodiversity' was the most studied subdiscipline. Baseline taxonomic studies in 'Zoology' and 'Botany' received little interest, particularly in 2006–2016. For 'Conservation biology', studies focusing on 'protected areas' were more numerous than for any other subsector, followed by 'biodiversity surveys'. Our analysis revealed that there were significantly more studies focusing on forests than on mangrove areas. Our results pointed out that, there is an urgent need for more rigorous taxonomical and fine-scale distribution studies of organisms across the whole region, not only for the traditionally overlooked groups (e.g. invertebrates). It is also stressed that studies of macropatterns in conservation biology research for the region should be performed by more reliable data at the more local scale, given the misuse that has been done by general studies of these limited/biased data for inferring patterns. Long-term longitudinal studies on biodiversity patterns of important forest sites and population biology of selected populations are urgently needed, as these have been almost entirely neglected to date. Crucial issues are still to be solved: for instance, it remains fully unresolved whether wildlife can best be protected through the promotion of human economic development or through integral conservation of important biodiversity areas.

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1. Introduction

The Guinean forests of West Africa (GFWA) form a belt of tropical moist broadleaf forests along the coast, extending from Sierra Leone and Guinea in the west, to the Sanaga River of Cameroon in the east (Fig. 1). These forests are among the most mega-diverse regions of the world (Myers, 1998; Myers et al., 2000; Oates et al., 2004), containing an exceptional diversity and endemism of vascular plants, as well as vertebrates and invertebrates (e.g., Kingdon, 1990; Myers, 1998; Myers et al., 2000; Oates, 2011). The GFWA is considered an important biodiversity hotspot (Myers, 1998; Oates, 1999; Myers et al., 2000), in which nine distinct ecoregions are recognised (Critical Ecosystem Partnership Fund, 2015). Ensuring the long-term survival of the GFWA is of global conservation concern (Oates, 1999). Moreover, since the GFWA is one of the most economically developed regions in Africa and the one with the highest human population density (De Montclos, 1994), applied ecological studies are of prime importance.

A number of factors act together against the long-term survival of the GFWA region. A major threat which directly and indirectly affects this region is the impact of industrial exploitation of natural resources, as witnessed by the numerous petrochemical installations in the Niger Delta, one of the main areas for refining and processing petroleum or natural gas in the world (De Montclos, 1994; Niger Delta Environmental Survey, 1998; GEF, 2010). Secondly, globally important forest products such as cacao (World Bank Group Country Survey, 2014) and palm oil (De Montclos, 1994; Akani et al., 2008) have been responsible for the loss of forest in the region; over 60% of the world's cacao exports originate from this region, particularly from the Ivory Coast and Ghana. Thirdly, considerable exploitation of forest animals for domestic consumption and the bushmeat trade has had and is still impacting the wildlife of the region (e.g., Fa et al., 2006; GEF, 2010). Fourthly, the demographic growth of some parts of the GFWA region (especially in southern Nigeria) has been among the fastest in the whole world (De Montclos, 1994; Niger Delta Environmental Survey, 1998; GEF, 2010). Last but not least, the GFWA region has been affected by serious epidemic diseases that appear to be somehow related to the forest ecology (e.g., the 2014–2015 Ebola virus outbreak that caused around 9000 deaths in the westernmost sector of this region; World Health Organization database available at<cdc.gov/vhf/ebola/outbreaks/2014-west-africa>).

Given the GFWA's intrinsic ecological values and also the concern for its long term survival, tropical ecologists and conservation biologists have shown much interest as seen in a considerable number of publications appearing in international journals and unpublished reports (e.g., Oates et al., 2004; Carr et al., 2014; Mallon et al., 2015). This critical mass of literature includes studies in community ecology, conservation biology, pollution, ecological economy, freshwater biology, as well as the relationship between wildlife and human diseases. No attempt has been undertaken at summarizing or systematically analysing this wealth of information. By performing such tasks it is possible to identify whether there are particular areas/subjects that need to be immediately explored because of data scarcity, and determine whether the available information can be used to develop strategies for the sustainable use of the natural resources in the decades to come.

In this paper we (1) present the results of a systematic review on the scientific literature available on the ecology and conservation of the GFWA region, (2) summarize the main sources of information available, discuss points of controversy, and (3) suggest possible next steps for pure and applied scientific research in the near future.

2. Methods

We carried out a systematic review using Google Scholar of published peer-reviewed scientific studies undertaken in the GFWA region under various ecological and biological conservation research themes. As a first step, we performed a Google Scholar search on 11 January 2017, using the following keywords: "Guinean Forest Mangrove" + one of the following disciplinary sectors in turn: 'Ecology', 'Zoology', 'Botany', 'Conservation Biology', 'Pollution', 'Climate Change', and 'Ecological Economy'. We included peer-reviewed articles published in international as well as in local journals, academic dissertations (Masters and PhD theses), books, conference proceedings, as well industry/multilateral agency reports (FAO, UNDP, UNEP, IUCN, CITES, etc).

From the results of this first search we tallied the total number of studies for each combination of key words, by time periods (pre-2005, 2006–2016) and by country. In a second Google Scholar search, we pooled "Guinean Forest Mangrove" with one of the following keywords: 'community ecology', 'autoecology and diseases ecology', 'theoretical ecology', 'methods in ecology', and 'macroecology and biogeography' for the disciplinary sector 'Ecology'; 'mammals', 'birds', amphibians and reptiles', 'fish', and 'invertebrates' for 'Zoology'; 'vascular plants', 'fungi' and 'algae' for 'Botany'; 'biodiversity surveys', 'community-based conservation', 'red-list assessments', 'protected areas' and 'bushmeat' for 'Conservation biology'. Studies were checked for relevance if they: (1) reported raw data that can be statistically analyzed or some explicit considerations/opinions/observations on the above-mentioned disciplinary sectors for the study region; (2) contributed data/considerations/opinions/observations that were clearly attributable to one or more of the following vegetation zones: mangroves, forest, forest-derived savannahs, and forest-plantation mosaics; (3) contributed data/considerations/opinions/observations that were not for whole countries (e.g. we considered studies presenting data for the Niger Delta area but not for the whole of Nigeria).

3. Results

The electronic search identified over 112,000 results for 17 disciplines (Table 1). The largest proportion (36.5%) of published studies focussed on 'Ecology', 'Climate change' and 'Ecological economy', but 'Zoology' had the least number of records with just over 4000 results (Table 1). For the period 2006–2016, an average of 60.4± 2.2% (mean ± 1 S.D) of all studies were typical for all disciplines though lower (52.5± 2.0%) for 'Zoology' and 'Botany' (Table 1).

By country, the largest number of studies was reported for Nigeria, Cameroon and Togo, and lowest for Guinea, Liberia, and

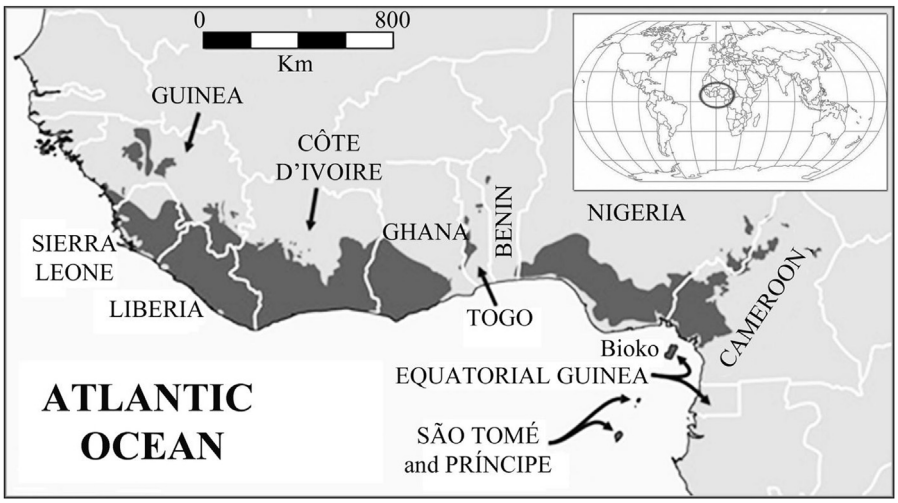

Fig. 1. Map showing the distribution of Guinean Forests of West Africa (modified from Critical Ecosystem Partnership Fund, 2015).

Sierra Leone (Fig. 2). There was a clear West to East trend for all seven disciplines (Ecology: $r = 0.78$, $P < 0.05$; Zoology: $r = 0.69$, $P < 0.05$; Botany: $r = 0.74$, $P < 0.05$; Conservation biology: $r = 0.72$, $P < 0.05$; Pollution: $r = 0.74$, $P < 0.05$; Climate change: $r = 0.74$, $P < 0.05$; Ecological economy: $r = 0.76$, $P < 0.01$), although Benin was significantly less studied than Togo, Nigeria and Cameroon (Fig. 2). A heterogeneity of slopes test indicated that the increasing number of studies by country from West towards East (expressed by the various regression lines in Fig. 3) was not significantly different among the various disciplines (one-way ANCOVA: $F_{6,55} = 1.427$; $P = 0.223$).

During 2006–2016, within 'Ecology' 'macroecology and biodiversity' was the most studied (over 77% of the total number of studies) compared to other subdisciplines (range 60.08–61.19% (Table 2). For 'Zoology', although fish and birds were the most studied taxonomic groups (Table 2), all subsectors received a similar research effort during 2006–2016, with bird studies slightly lagging behind. In contrast, there was a clear increase in 'Botany' studies, particularly on algae in 2006–2016 compared to vascular plants and fungi (Table 2). For 'Conservation biology', studies focusing on 'protected areas' were more numerous than for any other subsector (followed by 'biodiversity surveys'), with 'bushmeat' studies being by far the least numerous. However, studies on 'bushmeat' increased substantially in the period 2006–2016 in comparison with the other subsectors.

We found more studies focusing on forests than on mangrove areas (Mann-Whitney U test: $z = -3.592$, $P < 0.0001$), with no difference among countries and disciplines (in all cases, $P > 0.1$).

Studies on climate change represented a very small percentage of studies for Togo, but high percentages of studies for other countries such as, e.g. Ghana or Nigeria (Fig. 4). Overall, the frequency of studies on climate change varied significantly across countries ($P < 0.05$ at X^2 test), whereas there were no significant differencs across countries as for the other disciplinary sectors (in all cases, $P > 0.15$ at X^2 test).

4. Discussion

4.1. The geographic pattern in published studies

A main finding in our study was the clear difference between the West and East of the GFWA region in terms of the number of studies published within the seven disciplines examined. For all countries, most publications were in 'Ecology', with the three top countries being Nigeria, Cameroon and, despite its small size and reduced forest area, Togo (Ern, 1979). An explanation for this observation is that pre-2006, during the German colonization period (1884–1914) Togo was included in the Volta Region of Ghana, hence several Google Scholar results would have been assigned this country to Ghana had we used post-colonial political limits (e.g., Matschie, 1899; Schwarz, 1920; Owusu-Ansah, 2008). In addition, the Bismarckburg biological research station in southwestern Togo was responsible for much research in this country (Matschie, 1893; Amori et al., 2016).

The non-random 'longitudinal' pattern could not be explained either in terms of colonial-derived tradition or in terms of current economy. The three most studied countries were former French colonies (Cameroon and Togo) or British colonies (Nigeria). Among the four most economically developed and rich countries in the GFWA region (World Bank Group Country Survey, 2014 dataset),

Table 1
Summary of the Google Scholar search using habitat + region + disciplinary sector as 'key words'. For more details, see the text.

Habitats	Region	Disciplinary Sector	Total No. Results	2006–2016	%
Guinean Forest Mangrove	West Africa	Ecology	13600	8050	59.19
Guinean Forest Mangrove	West Africa	Zoology	4080	2160	52.94
Guinean Forest Mangrove	West Africa	Botany	6040	3030	50.17
Guinean Forest Mangrove	West Africa	Conservation Biology	8810	5590	63.45
Guinean Forest Mangrove	West Africa	Pollution	6970	4240	60.83
Guinean Forest Mangrove	West Africa	Climate Change	13600	7810	57.43
Guinean Forest Mangrove	West Africa	Ecological Economy	10400	6340	60.96

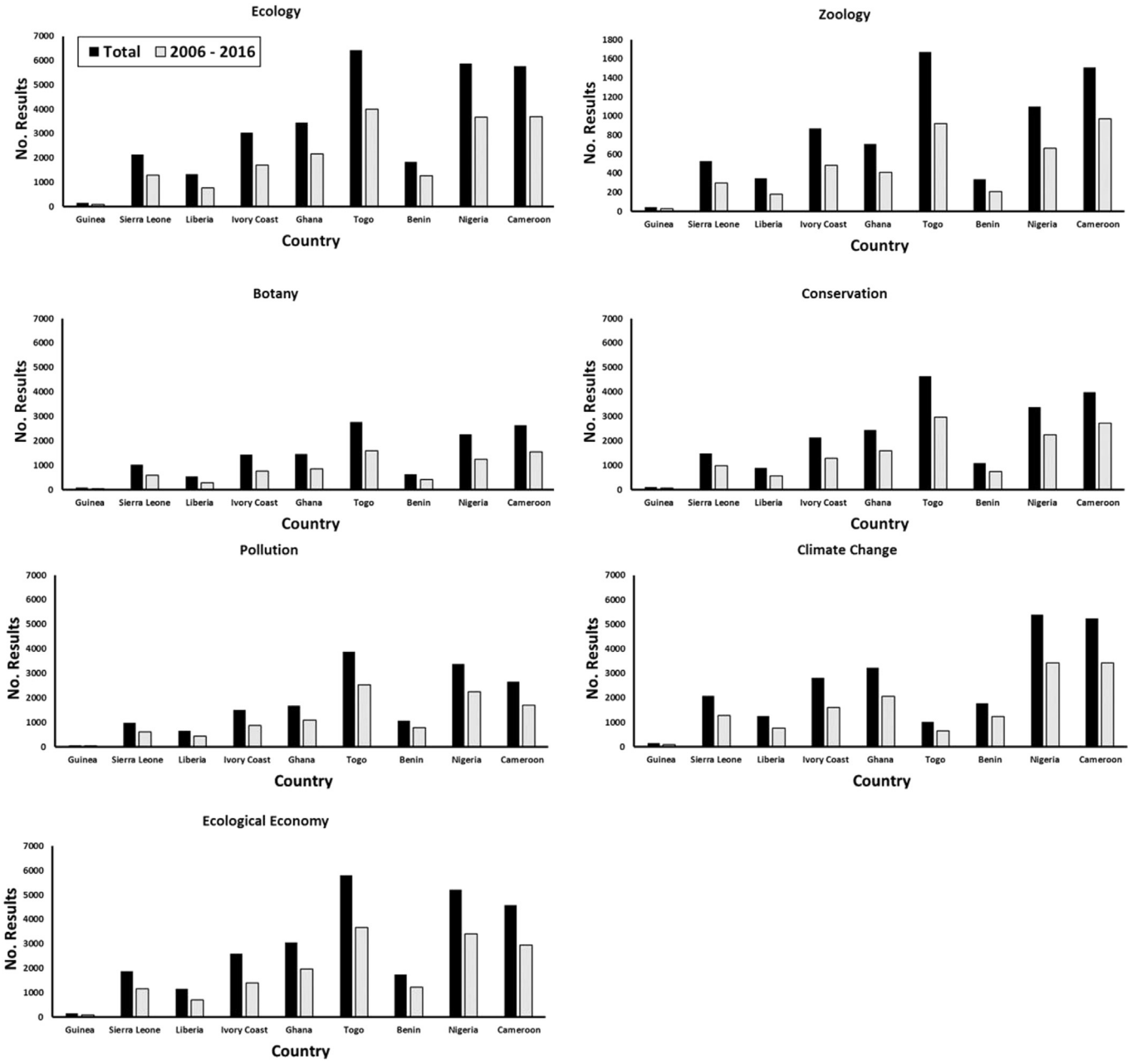

Fig. 2. Distribution of the number of results in Google Scholar by country and by time interval (total versus interval 2006–2016), for each of the various disciplinary sectors analyzed in the present paper.

two were among the most studied (Nigeria and Cameroon) and two were clearly least studied (Ivory Coast and Ghana). However, among the longest running tropical community ecology studies in the world, by Robert Barbault and his team, during the 1970s and 1980s, have been undertaken in Ivory Coast (Luiselli, 2007). The observed patterns did not even mirror the overall scientific/technical production of the various countries. Indeed, if we use the SCOPUS statistics (available at < http://www.scimagojr.com/countryrank.php>, last accessed on 24 January 2017), Nigeria leads the ranks (being at the 52th position in the world) and is also among the top countries for all disciplines, but Togo performs comparatively better (despite being ranked 143rd overall) than Cameroon (ranked 89th position), Ghana (86th), Ivory Coast (107th), or the neighbouring Benin (115th). These patterns indicate the complex relationship between each of these countries' colonial past, current economic situation and interest by international scientists.

4.2. Forests versus mangroves

Our analyses revealed that for all countries forest habitats (including forest-plantation mosaics) were consistently better studied than mangrove habitats, with no difference among disciplines. This result is expected given that mangroves are possibly one of the least studied terrestrial tropical environments, despite being seriously threatened worldwide (Valiela et al., 2001; Wilkie

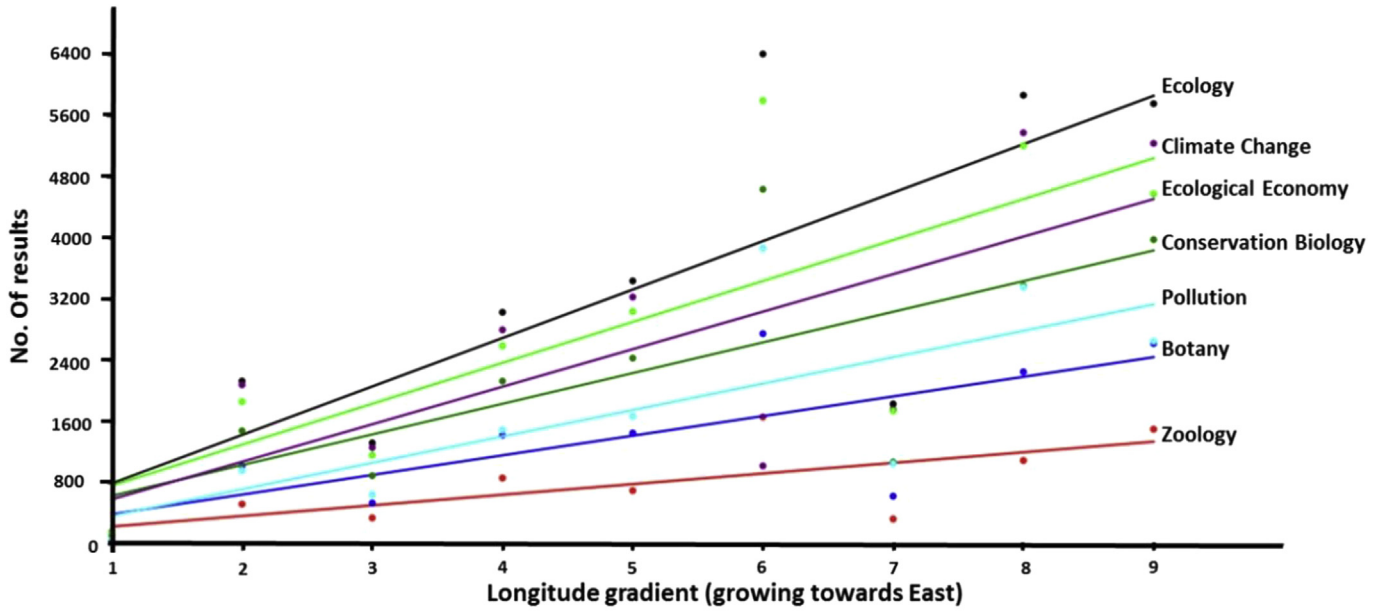

Fig. 3. Relationships between longitudinal gradient (1 = Guinea; 2 = Sierra Leone; 3 = Liberia; 4 = Ivory Coast; 5 = Ghana; 6 = Togo; 7 = Benin; 8 = Nigeria; 9 = Cameroon) and total number of results for Google Scholar searches by disciplinary sector. For the statistical details, see the text.

Table 2
Summary of the results of the Google Scholar search using habitat + region + disciplinary subsector as 'key words'. For more details, see the text.

Habitats	Region	Disciplinary Sector	Subsector	Total No. Results	2006–2016	%
Guinean Forest Mangrove	West Africa	Ecology	Community Ecology	11500	6970	60.61
Guinean Forest Mangrove	West Africa	Ecology	Autoecology	10600	6370	60.09
Guinean Forest Mangrove	West Africa	Ecology	Theoretical Ecology	6750	4130	61.19
Guinean Forest Mangrove	West Africa	Ecology	Methods In Ecology	12000	7230	60.25
Guinean Forest Mangrove	West Africa	Ecology	Macroecology and Biogeography	171	132	77.19
Guinean Forest Mangrove	West Africa	Zoology	Mammals	5800	3340	57.59
Guinean Forest Mangrove	West Africa	Zoology	Birds	9630	5020	52.13
Guinean Forest Mangrove	West Africa	Zoology	Reptiles and Amphibians	1960	1160	59.18
Guinean Forest Mangrove	West Africa	Zoology	Fish	12000	6760	56.33
Guinean Forest Mangrove	West Africa	Zoology	Invertebrates	3740	2220	59.36
Guinean Forest Mangrove	West Africa	Botany	Vascular Plants	2060	1020	49.51
Guinean Forest Mangrove	West Africa	Botany	Fungi	3570	1930	54.06
Guinean Forest Mangrove	West Africa	Botany	Algae	3860	2220	57.51
Guinean Forest Mangrove	West Africa	Conservation Biology	Biodiversity Surveys	6260	4360	69.65
Guinean Forest Mangrove	West Africa	Conservation Biology	Community-Based Conservation	2300	1570	68.26
Guinean Forest Mangrove	West Africa	Conservation Biology	Red List Assessments	5510	3370	61.16
Guinean Forest Mangrove	West Africa	Conservation Biology	Protected Areas	13500	7780	57.63
Guinean Forest Mangrove	West Africa	Conservation Biology	Bushmeat	845	584	69.11

and Fortune, 2003). However, considering that mangroves represent a crucial environment in West Africa with the Niger Delta mangrove belt (about 654,000 ha) being the largest in Africa and the 5th largest of the world (Giri et al., 2011), much more research should be focussed on this ecosystem. In particular, studies on the need to balance the survival of mangroves and the needs of the human populations are urgently needed e.g. areas such as the Niger Delta, where some of the largest industrial installations (oil extraction facilities by multinational oil companies) are found in mangrove areas, and where some of the poorest human communities can be found (e.g., Niger Delta Environmental Survey (NDES, 1998). Moreover, the coastal barrier islands of the Niger Delta in southern Nigeria, surrounded by the mangrove belt, are primary conservation areas for several large mammals that are already extirpated from all of the other environments of the region (Luiselli et al., 2015).

4.3. Baseline research topics in the GFWA region: forgotten but fundamental

Our analyses showed a conspicuous lesser interest on baseline taxonomic studies of GFWA zoology and botany in recent years, in contrast to ecology, conservation biology, pollution, ecological economy and climate change. This is a general trend in modern biological sciences worldwide (Andreone et al., 2014). But, given the fact that new amphibians (e.g., Rödel and Bangoura, 2004; Barej et al., 2015), reptiles (e.g., Bauer et al., 2006), and even mammals (Colyn et al., 2010) are still been described in the GFWA region, and that the status of several West African populations of widespread species is still in dispute, e.g. West African bushbuck (*Tragelaphus phaleratus* or *T. scriptus*) and sitatungas (*Tragelaphus gratus* or *T. spekii*) (Groves and Grubb, 2011), the need for more taxonomic studies becomes apparent. Moreover, even in one of the most

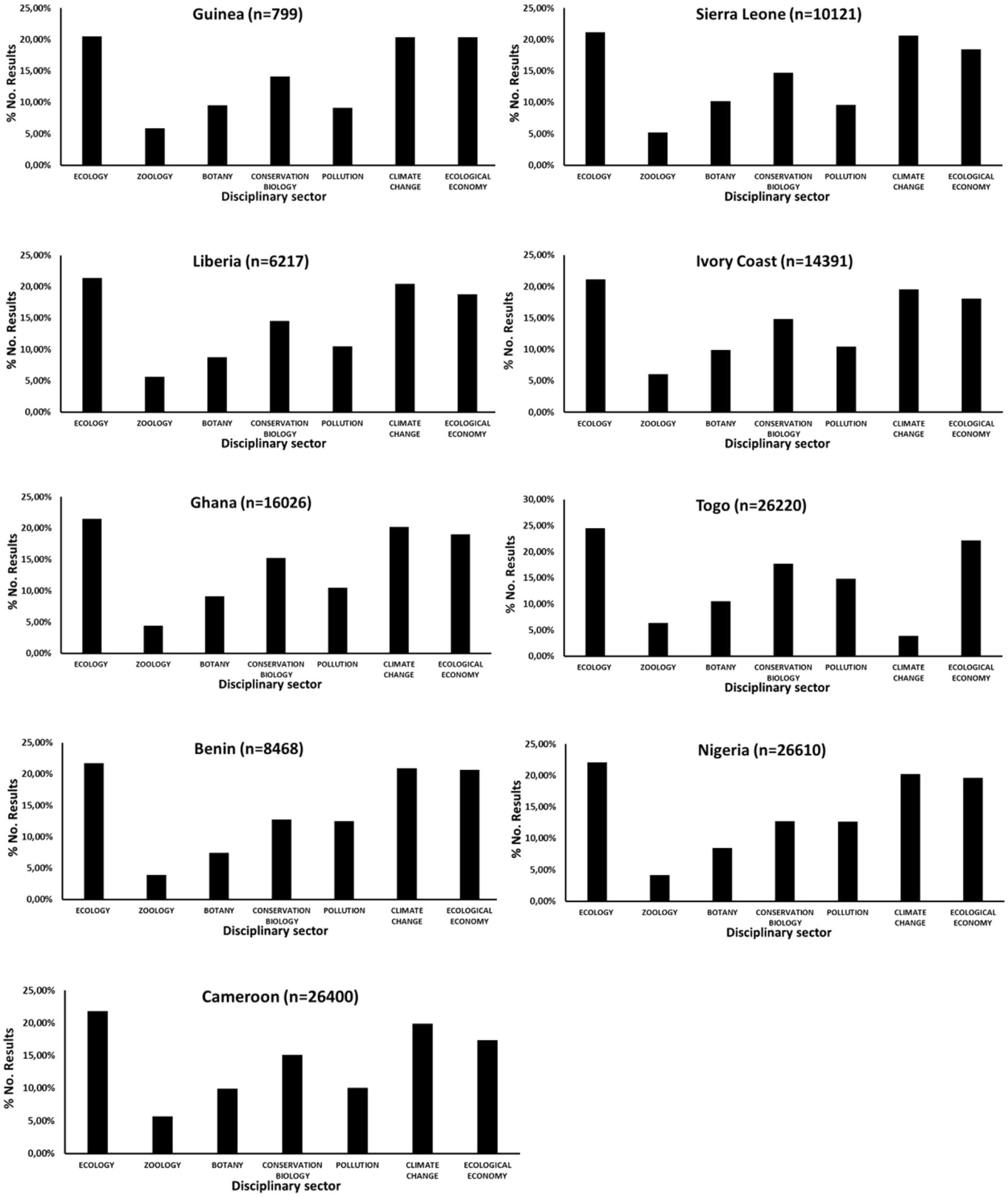

Fig. 4. Distribution of the percent number of results (after Google Scholar searches) of the various disciplinary sectors in each West African country studied in this paper.

intensively surveyed areas (Niger Delta, southern Nigeria), Luiselli et al. (2015) highlighted remarkable inaccuracies with the available literature. As many as 16 out of the 65 (24.6%) medium to large sized mammals censused in the area since 1995 (Blench, 2007; Angelici et al., 1999), were wrongly/unsubstantially cited as occurring in the area, with no vouchers or photographic documentation available in public repositories. These problems were particularly serious for duikers (genera *Cephalophus* and *Philantomba*), as only one of the six species cited in the above-mentioned literature are definitely present in the Niger Delta region (Petrozzi et al., 2015). The consequences of these inaccuracies in baseline zoological data are significant, for instance, how many mammal species have been extirpated from the Niger Delta region during the last 20 years (because of habitat loss, development operations and overhunting) is still unknown. In addition, the inaccurate use of many toponyms over the decades, such as the toponym 'Adéle' for the biologically famous Togolese locality called 'Bismarckburg' during colonial times (Amori et al., 2016) has created much confusion, thus making it absolutely fundamental the need for baseline studies on the zoological and botanical characteristics of all areas within the GFWA region.

4.4. Finer-scale patterns and knowledge gaps by disciplinary sectors

An analysis by disciplinary sector can highlight finer-scale patterns and gaps concerning our knowledge of the GFWA region. Overall, ecological studies (including diseases ecology in their subsectors) are the most represented in our Google Scholar search, especially in Togo and Nigeria, but least in Guinea, Liberia, and Benin (Fig. 2). This variation among countries indicates that research efforts vary significantly, since in countries like Nigeria the number of Google Scholar results by subsector is similar, but in others there were clear differences across subsectors; studies in 'Theoretical ecology', 'Community ecology', and 'Methods in ecology' are virtually absent in the Westernmost GFWA countries. In addition, whilst for some areas of the GFWA (Nigeria and Cameroon) ecological studies were often based on explicitly stated hypotheses and/or used sophisticated statistical techniques (e.g., Monte Carlo algorithms, occupancy methods and logistic regression modeling issues, see Luiselli, 2006a, 2006b, 2006c), for other parts of the region (Guinea, Liberia) mostly descriptive studies were published (data coming from our examination of the available literature). Thus, a main priority for 'ecology' research in GFWA would be to promote more hypothesis-driven studies, particularly in mangrove areas and in countries other than Nigeria and Cameroon.

For 'Zoology' and 'Botany', as pointed out above, there is an urgent need for more rigorous taxonomical and fine-scale distribution studies across the whole region, not only for the traditionally overlooked groups (e.g. invertebrates in freshwater and terrestrial habitats) but also for the better studied taxa, as there are very confusing information available in the scientific literature (see above). In addition, baseline taxonomic studies of species still occurring in forest fragments of the Dahomey Gap, in Benin, Togo and Western Ghana, based on molecular genetics, are required given that population differentiation is likely in these isolated forest fragments (e.g., Groves and Grubb, 2011).

Within 'Conservation biology', there are several lines of research that may be potentially very relevant in years to come. Overall understanding of macropatterns in conservation biology research for the region has probably been negatively affected by the poor quality data available at the more local scale, and also by the misuse of these limited/biased data for inferring patterns. For instance, some studies at the continental scale (e.g., Rondinini et al., 2005) clearly underestimated the 'effective protection' given to species by the available network of protected areas because these studies (1) used merely the 'official national parks and protected areas', (2) for most (if not all) protected areas the list of known species is very incomplete (once more, an exception is Nigeria with several studies published on selected taxa of various protected areas; e.g. Akani et al., 2014, 2015), and (3) the complicated network of community-based protected areas (Chandrakanth and Romm, 1991) is ignored by these analyses. There are hundreds of forest sites that are not formally protected by governments, but local communities assure effective 'traditional protection' and especially for some 'taboo' species (e.g., Decher, 1997; Luiselli, 2003). On the other hand, because poaching and illegal timbering are still rampant inside officially protected areas (e.g., Eniang et al., 2008), these persistent threats are not taken into account when planning future conservation actions in the GFWA region.

As in several other tropical regions, much of the GFWA research in conservation biology has concentrated on biodiversity surveys of some forest patches and/or protected areas, either through remote sensing (Laurin et al., 2014) or field investigations (e.g., Abban, 2009; Siaw and Dabo, 2009; Bi et al., 2010), mainly focusing on charismatic animals (e.g., Demey and Rainey, 2004; Norris et al., 2010; Buzzard and Parker, 2012). However, most published studies have rarely investigated how the species composition of a given forest/protected area (Waltert et al., 2002) may change over time due to human intervention, thus making it impossibile to generalize patterns in the evolution/taxonomical simplification of biotic communities resulting from habitat loss and overexploitation (Petrozzi et al., 2015). In Nigeria, however, several studies are available on how herpetological communities have changed in selected forest areas (Lea et al., 2003, 2005). Thus, to properly evaluate/monitor the intervening changes in the biotic communities in important GFWA sites, it is crucial to plan quantitative surveys at discrete but constant time intervals (for instance, once every 5–10 years) using standardized field methods and efforts. Rapid assessment surveys, following the protocols suggested by Conservation International, or RAPELD procedures, may be useful for quantitative comparisons across distinct sites, in order to generalize the observed patterns at a larger scale.

In general, the scarcity of long-term 'longitudinal' studies to assess conservation biology issues in the GFWA is a major shortcoming for the appropriate management of these forests and of their wildlife (Oates, 2011). However, a few long-term studies (on demography of snakes in the Niger Delta, see Reading et al., 2010; and on the bushmeat trade dynamics in single market places, see McNamara et al., 2015) are already available for the study region, and others should be planned and conducted.

The most worrying issue is that, after some decades of field studies and researches in the GFWA region, it seems that none of the most crucial conservation biology questions has been adequately answered. For instance, it remains fully unresolved whether wildlife can best be protected through the promotion of human economic development (e.g., Prins et al., 2000) or through absolute conservation of important biodiversity areas (Oates, 2011), with human well-being being to be promoted by large-scale political, social, and economic reforms than by community development schemes associated with conservation projects (as proposed by Oates, 2011). It remains also unresolved, and still much questionable, whether human communities living in extreme poverty impact forest environments more heavily than wealthier communities or vice versa. The answer to this issue may depends also on the scale that is taken into account, among other things, and it is very unlikely to have an ecological answer not considering also the social and political context. And again, it is not resolved, and still very much questionable, whether bushmeat is a luxury good or

whether it is associated with extreme poverty. Resolution of these key questions would improve future conservation strategies for the GFWA region, though more research is needed. We suggest that planning future studies should take into account methods that can adequately answer key conservation questions to improve the effective management of the GFWA region.

Pollution and climate change studies should also be further strengthened, with particular attention to local-scale case studies rather than predictive models that often have serious caveats and shortcomings. For instance, the available studies of climate change effects on GFWA biodiversity either use predictive scenarios to infer distribution contractions of selected species (e.g., Bombi et al., 2011) or use expert-based assessments of species-specific life-history traits to explore a species' specific vulnerability to climate change (e.g., Carr et al., 2014). There are several theoretical issues that make these analyses contentious without solid field data on the ecophysiology of the species concerned (e.g., Ujivari et al., 2012). Although Carr et al. (2014) approach is very promising, the (almost) total absence of true data on life history traits and climate change vulnerability for many species makes this approach a mere theoretical exercise of potentially low relevance to the 'real world'. Therefore, basic studies in conservation ecophysiology are essential to help build a more solid climate change vulnerability dataset for the GFWA species.

In terms of published data on the ecological economy of the GFWA region, it seems that the same concept proposed by Costanza et al. (1991) does apply: "the most obvious danger of ignoring the role of nature in economics is that nature is the economy's life support system". In fact, although our analyses revealed a growing number of studies in this disciplinary sector, most of these studies focused on environmental sustainability aspects of a given economic output. Indeed, there are many more studies on sustainable economy, green economy and environmental economy, than studies taking into account the ecological economics with the idea of preserving the natural capital as part of an economic system. The time frame of ecological sustainability is not taken into account, but rather the sustainability is used as an element for measuring the impact on the environment in a specific economic activity that becomes sustainable when it minimizes the environmental effort. The change of vision that sees ecology, as a productive crucial factor in an economic system has not yet been sufficiently investigated. Further investigations should be made in terms of accounting calculation to monetize the damage caused by economic activities, in order to quantify the economic cost of restoring the original environmental conditions when and where possible. Moreover, the environmental damage economic accounting should be investigated by analysing the impacts on socio-economic conditions of local populations. An example are the oil palm plantations in West Africa, where large plantations have taken the place of the forest in a short period (dataset available at < sustainablepalmoil.org/Africa/ >) to undertake productive investment income that have seen the involvement of large foreign capital but which have never been evaluated in terms of loss of forest and biodiversity both locally and globally. Also, it has never been assessed what are the damages of natural capital loss in microeconomic terms, in order to investigate the effects of the biodiversity loss in term of local income distribution. These innovative fields of investigation should be explored in detail in the future years.

Authors' contributions

LL, GCA, BBF and JEF designed the study; DD provided the data; LL and EAE analyzed the data; LL and JEF drafted the paper; all authors corrected and improved the written manuscript.

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